MISCELLANEOUS PAPER NO. 4-791 ~~4-78~~

REPORT OF CONFERENCE OF THE BOARD OF CONSULTANTS ON REMOTE TERRAIN ANALYSIS BY ELECTROMAGNETIC MEANS

Waterways Experiment Station
18 - 19 November 1965

February 1966

Sponsored by

U. S. Army Materiel Command

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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ARMY-MRC VICKSBURG, MISS.

I

CONTENTS

REPORT OF CONFERENCE OF THE

BOARD OF CONSULTANTS ON REMOTE TERRAIN

ANALYSIS BY ELECTROMAGNETIC MEANS

Waterways Experiment Station

18-19 November 1965

1. A conference of the Board of Consultants on Remote Terrain Analysis by Electromagnetic Means was held at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, on 18-19 November 1965. Only summaries of the technical papers presented are given herein; complete texts of these presentations of test programs and results to date will be published as WES technical reports under the general title Terrain Analysis by Electromagnetic Means. Exhibit 1 is the program for the meeting, and Exhibit 2 is a list of attendants. Exhibit 3 describes proposed future plans. Exhibit 4 presents the report prepared by the Board of Consultants at the conclusion of the conference.

2. Colonel John R. Oswalt, Jr., Director, opened the meeting by welcoming the Board members and visiting officials to WES. He expressed regret that he would need to divide his time among three conferences, but said he would meet with this group for short periods as the meeting progressed. Colonel Oswalt extended an invitation to the consultants and visitors to visit other WES facilities of particular interest to them if time permitted.

3. Mr. Shockley, Chief of the Mobility and Environmental Division, WES, explained the program, emphasizing that it was a full one and one which he hoped would provoke discussion. He said that he felt it necessary to confine the discussions to the time limits designated, and pointed out that a time had been set aside on 19 November for the consultants to compile their report. Mr. Shockley asked the consultants to elect a chairman who would be the spokesman for the group and responsible for ensuring that their recommendations were reviewed, drafted, and submitted to WES as a formal report from the Board. He requested that an informal presentation of this report be made to the conference at the final session.

4. Mr. Shockley began the technical portion of the meeting with a brief discussion of the remote sensing techniques under investigation by

the Terrain Analyzer Section and their relation to the area evaluation, mobility, and trafficability studies conducted at WES under the sponsorship of the U. S. Army Materiel Command.

5. Brief summaries of the technical papers presented, together with the subsequent discussions, are presented in the following paragraphs.

Infrared Studies

"Laboratory Investigations in the
0.76- to 5.00-Micron Spectral Region"
(B. R. Davis)

6. More than 800 laboratory-prepared soil samples were tested to determine whether correlations could be established between the quantity of infrared energy reflected from soils and soil parameters pertinent to trafficability. A reflectance spectrophotometer operated conjunctively with a carbon arc source of radiation was used in the tests. The trafficability parameters of primary concern were moisture content, density, and soil type. It was shown that generally an increase in moisture content resulted in a decrease in reflectance regardless of wavelength. However, for soil at high moisture contents (which is a range of special interest in terms of trafficability), the change in reflectance at any given wavelength resulting from a change in moisture content was not great enough for the relation to be used to determine the moisture content precisely.

7. A technique employing comparison of reflectance at six different infrared wavelengths was discussed as a possible method for determining the soil type and moisture content of laboratory-prepared, homogeneous samples. This method, and the problems involved in its application to field measurements, demonstrated the necessity for using multisensor or multiwavelength sensing systems for remote terrain analysis.

8. It was pointed out and verified with data that since penetration characteristics of infrared radiation are negligible, the reflectance was practically unaffected by density.

"Laboratory Investigations of
the Infrared Emittance of Soils"
(H. J. Lavecchia)

9. Data from tests conducted using an infrared camera were analyzed

to determine whether correlations could be found between the infrared emittance of a soil and its composition and surface moisture content. Problems in relating soil emittance to the optical density of the image produced were cited, and the following disadvantages were given as reasons for abandoning the imaging method and replacing it with waveform measurements:

a. The imaging method provided no correction for the contribution of radiation incident on the soil sample.

b. Changes in detector-preamplifier sensitivity introduced ambiguity in the tone density of the image.

c. Changes in the surface temperature of the soil sample occurred during the image-forming process.

10. The emittance of a soil sample was determined by waveform measurements of the soil sample and two reference gray bodies measured consecutively. The manner of measurement was discussed in detail in the presentation. The infrared measurements were shown to vary systematically with changes in the moisture content of a soil. This substantiated the results of the active infrared studies; however, the method of obtaining passive infrared measurements was tedious and complicated and not easily applicable outside the controlled conditions of the laboratory.

Discussion

11. Dr. Colwell asked Mr. Davis if he had tried to find any correlation between infrared reflectances and volumetric measurements of water. Mr. Davis referred Dr. Colwell to WES Technical Report No. 3-693, Report 1, Terrain Analysis by Electromagnetic Means; Laboratory Investigations in the 0.76- to 5.00-Micron Spectral Region, in which infrared reflectance is compared to three different measures of moisture content. These were: reflectance versus moisture content in percent of dry weight of soil, reflectance versus percent saturation, and reflectance versus pounds of water per cubic foot of soil. There was no significant advantage attendant to any one of the three measures used; therefore, moisture content as a percent of dry soil weight was chosen, since it was the most commonly used by engineers concerned with soil trafficability problems.

12. Dr. Feder asked if any compensation was made for the passive infrared radiation emitted by the test sample when active infrared reflectance was recorded. Mr. Davis said that, in his opinion, the radiation emitted by the carbon arc light source used in conjunction with the spectrophotometer

was of such high intensity that the small amount of radiation emitted by the test sample could be considered negligible.

13. Dr. Feder asked Mr. Davis if one reference at one wavelength was good for all wavelengths, and if the same procedure for testing was used every time. Mr. Davis replied that sometimes, for certain wavelengths, soil reflectance was greater than the reflectance from the standard reference (white plate glass). The reflectance of the standard reference for a wavelength of 1.94 microns was found to be nearest that of a perfect reflector; therefore, this reflectance was used as the standard. The purpose of the standard reference was to (a) ensure that the equipment was operating correctly and (b) make relative comparisons of data. The same procedure was used every time.

Gamma-Ray Studies

"Laboratory Investigations in the 0- to 2.819-Mev Gamma-Ray Spectral Region" (A. N. Williamson)

14. Laboratory tests were conducted in two phases to determine whether soil gamma-ray emission spectra could be correlated with trafficability factors. A low-background enclosure was used to isolate the soil sample from effects of variations in background radiation that might occur during testing. Measurements were made using an NaI scintillation crystal detector conjunctively with a multichannel pulse-height analyzer.

15. In the first phase, representative samples of sand, silt, and clay were tested. Consideration of the photopeak counting rates and the photopeak ratios of thallium, bismuth, and potassium showed that a proportionality existed between photopeak counts and moisture content and suggested that photopeak ratios might be useful in distinguishing soil types. In the second phase of the study, approximately 200 soil samples from all 50 states were tested to evaluate empirically the use of gamma radiation in determining soil type and other morphological, genetic, and physical-chemical characteristics. The results were examined to determine whether a relation existed between photopeak ratios of thallium, bismuth, and potassium and the following: parent material-geological type, parent material-geological age,

USDA Great Soil Group, soil textural class, USDA Soil Order - 7th Approximation, pH, land usage, and soil series. While the results to date had not shown any definite correlations, the analyses were not complete so no definite conclusions could be drawn.

Discussion

16. Dr. Colwell noticed that both thorium and thallium were discussed in the talk and wondered if this was proper usage. Mr. Williamson explained that thallium is a daughter product of thorium and was the isotope actually detected in gamma-ray measurements.

17. Dr. Feder asked if the spectrum correction matrix mentioned in the talk was equally usable on spectra obtained on an empty low-background enclosure and on an enclosure containing a soil sample. Mr. Williamson said that it was and added that it also appeared usable for measurements made outside the laboratory. Dr. Feder asked if outside measurements had been attempted with the spectrometer. Mr. Davis answered that some tests had been run outside the laboratory and the measured background, within the energy range of interest, was essentially the same as in the laboratory. Thus, the low-background enclosure inside the laboratory appeared to offer no real advantage. This was not studied in detail, however, since it was not of primary concern when the measurements outside the laboratory were made.

18. Dr. Feder asked if the potassium in the concrete at the top and bottom of the low-background enclosure contributed to the gamma-ray measurements. Mr. Davis said that the radiation was sufficient to be measured with the spectrometer, and that the potassium level was taken into account in the analysis.

19. Dr. Lattman stated that the gamma-ray spectra of soil constituents could be significantly different from those of the parent soil because of leaching, weathering, and so on. He asked if gamma-ray tests of different thicknesses of soils had been made. Mr. Lundien replied that tests, which are explained in detail in the report on laboratory gamma-ray measurements, indicated that the gamma-ray measurements were not significantly affected by subsurface characteristics at thicknesses exceeding 10 in. Dr. Barringer mentioned that his organization had flown over 1000 mi with a gamma-ray system and it was noted in these flights that granite showed up well and was

manifested by high potassium counts. The potassium source in the granite could be traced between outcrops. In addition, the gamma-ray counts indicated underlying soils with high radioactive constituents. Dr. Barringer concurred with Mr. Davis that a low-background enclosure was not necessary for laboratory tests.

20. Dr. Feder mentioned that gamma rays can be used to distinguish between sands, silts, and clays on a qualitative basis and that work of this nature has already been extrapolated to the field. Since the Terrain Analyzer Section has good equipment, Dr. Feder suggested that this equipment might be installed in an aircraft owned by some other agency, such as Texas Instruments Inc. or Barringer Research Ltd., that has the type of aircraft needed. Mr. Davis stated that plans of this nature already exist and, he hoped, will be implemented in the future with field tests using a truck-tower-mounted gamma-ray system and an airborne system conjunctively to monitor the gamma-ray characteristics of selected areas. In this manner, the problems of extrapolating from ground to airborne operations could be resolved.

Radar Studies

"Laboratory Radar Studies"
(J. R. Lundien)

21. Tests were conducted to study the effects of the physical parameters of soil and vegetation on the quantity of radar energy reflected from a soil sample. Signature and depth-of-penetration tests were made on large samples, with and without surface vegetation, prepared at several moisture contents and densities. Radar frequencies were 297, 5870, 9375, and 34543 megacycles per second.

22. These tests were analyzed on the basis of (a) the occurrence of a cyclic pattern resulting from the presence of subsurface reflection sources (P-band only), and (b) surface reflections that were measured in the absence of a detectable subsurface reflection component (Ka-, X-, and C-bands). The cyclic patterns obtained at P-band frequencies indicated the depth-of-penetration capabilities and could be correlated with the electrical properties of the soil. These, in turn, could be correlated with the soil physical properties that are of interest from a trafficability standpoint.

23. The following are findings from the analysis based on P-band:

a. As moisture content increases, the conductivity of the soil increases, but along a different curve, depending on soil type.

b. When the effects of conductivity (very small for the soils tested) are neglected, the relative dielectric constant increases at a rate dependent upon the soil type.

c. When relative dielectric constant is plotted versus moisture content expressed in lb per cu/ft, soil type per se has little influence.

d. The amplitude of subsurface layer reflections does not affect the value of relative dielectric constant.

e. Computed values of the relative dielectric constant for tap water at various temperatures agreed in general with textbook values for water. The difference of approximately 4 percent from textbook values was attributed to the use of tap water instead of distilled water for tests.

24. The surface reflection values from Ka-, X-, and C-band data can be used to obtain the relative dielectric constant of the soil because the soil-penetrating capabilities at these frequencies are limited. As the surface reflection increases, the relative dielectric constant increases.

25. Although the results of these laboratory tests show that useful correlation do exist, either the thickness or the dielectric constant of the sample must be known to be able to estimate the other. Since these can be controlled only in the laboratory, it was concluded that standard pulsed monochromatic radar systems are not suitable for remote analysis of terrain from a trafficability standpoint and that specially designed radar systems are needed for this purpose.

26. A variable-frequency radar system and its use in measuring subsurface soil conditions was explained in detail. The system would consist of a wide-band receiver and a variable-frequency transmitter. The signal received from the varying transmitted frequency would produce a cyclic pattern, which results from a variation of received signal as a function of frequency. By measuring the frequency difference between two adjacent minimums (or maximums) and estimating the relative dielectric constant from the average reflected power, the depth of a layer could be calculated. Preliminary laboratory results have shown that with this type of system, C- and X-band frequencies can be used to measure up to 12-in. thicknesses of dry sand overlying damp silty clay. The roughness of the surface manifests

itself only as an alteration in amplitude with no change in the cyclic pattern.

Discussion

27. Dr. Feder noted that the range gate was set halfway up the leading edge of the pulse in the slide presented. He thought this might not be the best procedure because the system was calibrated at peak power, but the pulse was read at a level less than peak power. Mr. Lundien explained that the middle of the pulse was receiving background energy because the system was located in a laboratory; therefore, the front end of the pulse was used in an effort to gate out as much background return as possible. He also stated that the value obtained for soil dielectric constant was not power dependent.

28. Dr. Feder asked if a microrelief study had been made. Mr. Lundien said that it had and that it was noted from this test that the reflectance from a sample having minor surface irregularities was lower than the reflectance from a smooth sample.

29. Dr. Bates asked if any work had been done with variable angles of incidence in order to measure the Brewster angle. Mr. Lundien replied that the tests were run at different angles of incidence, but the receiving and transmitting antennas were mounted in the same plane with respect to the test sample, which prohibited measurements of the Brewster angle. Mr. Lundien mentioned that the Brewster angle had been measured by radar systems using two airplanes.

30. Dr. Feder suggested that a monopulse radar system be considered for future testing. He acknowledged that a system needed to be developed to analyze data from the monopulse system, but he felt that the variable-frequency radar system discussed in the talk would be influenced by too many terrain factors.

31. Mr. Lundien stated that a simple variable-frequency system operating at X- and C-band frequencies had been used to measure depths up to 12 in. in dry Yuma sand, and that laboratory studies of soils using the variable-frequency radar system could be conducted with the facilities already available at WES.

32. Dr. Barringer stated that the multifrequency system is good because it can penetrate to different depths. He felt, however, that several design problems need to be resolved before either the variable-frequency or the

monopulse radar system will be practical for use in an aircraft installation. At the altitude and speed of the aircraft, resolution of small areas would be very difficult at present. Mr. Davis remarked that there are two major reasons why the WES had not progressed in the development of such a system. One is the lack of funds, which have been requested for some time with little success, and the other reason is that NASA recently awarded a contract for development of an airborne swept-frequency system to Dr. Barringer's company. The present plan is for that company to work out the "bugs" and improve the state of the art to a point where development of a field system would be somewhat routine. Mr. Davis added that the WES latest request for funds to develop a swept-frequency system has been assigned a high priority for FY 67 and that it is hoped that procurement action can be initiated next year.

Study of Air-Dropped Oscillators

"Development of Air-Dropped Oscillators
for Measurement of Soil Trafficability"
(P. A. Smith)

33. Air-dropped electromagnetic sensors that either penetrate into the soil or lie on the surface may be an interim answer to the problem of measuring trafficability by remote means. Data measured would be obtained through transmitters mounted in such sensors.

34. A development program was undertaken with two primary objectives:

a. To design and construct a prototype electronic sensor suitable for measuring the dielectric constant and conductivity of soils to depths up to 2 ft under field conditions.

b. To determine whether the values obtained could be correlated with soil type and moisture content.

35. A penetrometer was constructed which consists of a tubular shaft with a cone attached at one end. Pairs of electrodes mounted at 1-in. increments along the shaft of the penetrometer are used to indicate the depth to which penetration takes place. Capacitor plates 6 in. long are embedded in the shaft of the penetrometer. A tank circuit, consisting of the capacitor plates and suitable coils, is used in conjunction with specially designed electronic triggering circuits. This tank circuit oscillates at a frequency and decay rate determined by the characteristics of the soil surrounding the

plates. The frequency of the oscillations is used to determine the apparent relative dielectric constant of the soil; and the decay rate, or damping of the signal, is used to determine the apparent conductivity.

36. From field tests made with the penetrometer at 26 different sites, it was seen that apparent relative dielectric constant and apparent conductivity follow closely the profile of changes in moisture content of the soil. It also was observed that soil type has little effect on the apparent relative dielectric constant, which is primarily a function of the soil-moisture content.

Discussion

37. Dr. Feder asked if the dropped oscillator can measure the depth of penetration. Mr. Davis said that the present prototype can provide depth-of-penetration data accurately to within 1 in.

38. Dr. Feder asked if the instrument would be able to provide an accurate measure of soil conditions if it was used under adverse circumstances, such as those existing in a rice paddy in which half of the instrument was buried in soil and half in water. Mr. Davis replied that the instrument does not operate as a single unit, but is a system of smaller independent units. The oscillator measures dielectric constants at 6-in. increments, and depth of penetration at 1-in. increments.

39. Mr. Molineux said that it is possible for an aerial penetrometer to give wrong depth information if it penetrates the terrain at an angle of other than vertical incidence. Mr. Davis agreed that an inclined penetration would result in inaccurate depth data, but added that dielectric constant data would be correct.

40. Dr. Feder asked if the oscillator has to age in the soil before it can give accurate measurements. Dr. Lattman answered that the compaction of the soil that occurs as the instrument penetrates does not have any appreciable effect on the soil characteristics. Dr. Freitag stated that from studies that have been made on the effects of an object driven into the ground, no significant change of soil-moisture content in the zone of measurement was expected.

41. Dr. Lattman said that the amount of clay in a soil can have an adverse effect on a penetrometer-type instrument because the instrument can

be lubricated by a coating of clay during penetration, thus giving a false measurement of soil strength.

42. Dr. Lattman questioned the scattering of points in slide 5 used by Mr. Smith with his talk. Mr. Smith said that the scattering probably was due to nonuniform contact between the soil and the plates of the penetrometer during testing.

43. Dr. Barringer stated that results of tests conducted with drill core material showed that electrode contact with the soil greatly affected the dielectric constant. He asked if electrode effect would be a factor in measuring the dielectric constant of soils with the dropped oscillator. Dr. Nikodem replied that the electrode effect is eliminated by insulating the electrodes from direct contact with the soil.

44. Dr. Lattman noted that many arid or semiarid soils have hard surfaces, but the underlying soil is not continuously hard. This type of soil would create a problem for any air-dropped instrument. Mr. Davis stated that the air-dropped oscillator is to be used as part of a multisensor system, and any shortcoming of one sensor, such as the penetrometer, would perhaps be overcome by some other sensor or combination of sensors. Mr. Shockley pointed out that a number of oscillators would have to be dropped to gather information from large areas.

45. Dr. Lattman asked if the target had to be sampled with slow-flying aircraft. Mr. Molineux answered that fast-flying jets have been used to drop penetrometers into areas of about 300 sq ft.

Theoretical Study of Remote Sensing Limitations

"Factors Influencing Remote Determination of Soil Trafficability Conditions Using Radar and Radio Waves" (H. J. Nikodem)

46. The purpose of this study was to investigate means of using long-wavelength radar and radio frequencies to determine soil characteristics remotely. In general, thinking was directed toward the soil properties that can be measured, the measurement methods that are applicable, and the problems that arise from the use of certain wavelengths. Specifically, this study considered the following:

_a._ Which soil parameters interact with electromagnetic radiation and are these parameters related to the trafficability of the soil?

_b._ What influences do other terrain factors, such as vegetation, surface roughness, and large-scale profile deviations (hills and mountains), have on the radiation?

_c._ What influence does wave penetration through various soil layers have on the reflected radiation?

_d._ Which types of sensing devices are applicable to the problem?

_e._ What parameters can be measured?

_f._ To what extent are the assumptions made in this analysis realized in nature?

_g._ What is the effect of deviations from the assumed ideal conditions?

_h._ How can the different methods proposed for remote sensing be evaluated?

47. The influence of soil parameters, vegetation, surface roughness, and layers in soils on the electromagnetic wave reflected from various types of terrain were discussed. The applicability of different measuring devices such as monopulse, fixed-frequency, variable-frequency, and phase-measuring radio systems also was investigated.

48. Consideration of the influence of the various terrain parameters and evaluation of the sensors discussed herein led to the following conclusions:

_a._ No single system studied is equally applicable to all types of terrain. In fact, the disturbing influences of vegetation and complicated layer structures that exist in most parts of the land masses of the earth make a generally applicable system impossible.

_b._ Only beamed radiation appears promising for remote sensing in hilly terrain. Antenna dimensions limit the wavelength of the beamed radiation to something shorter than 1 meter.

_c._ In slightly undulating terrain, flights at low altitudes tend to minimize errors due to reflections from surfaces deviating from a plane (i.e. surface irregularities and changes in slope).

_d._ Vegetation cover limits absolute measurements to wavelengths between 1 and 3 meters, and ground-scattering experiments to wavelengths longer than 10 meters. For very-short-pulse or variable-frequency systems, wavelengths shorter than 1 meter might be applicable to measuring the optical thickness of soil layers underlying vegetation.

_e._ Very-short-pulse and variable-frequency systems can be used to determine the optical thickness of layers if a surface layer is

relatively smooth and plane and has a higher or lower refraction index than the second layer. When soils have very complex layers, very-short-pulse systems have some advantages over variable-frequency systems because they are able to eliminate the time-delayed reflected signals from layers several feet beneath the surface.

f. Soil-moisture content may be determined from the measured values of the reflection coefficient of the surface in homogeneous soil, where all systems studied can be used to derive the dielectric constant from which the moisture content can be determined, and in layered soils, where very-short-pulse and variable-frequency systems can be used.

g. It may be possible to determine soil-moisture content by deriving the dielectric constant from combined phase shift and reflection coefficient measurements, using wavelengths longer than 3 meters.

h. For rough soil surfaces, the dielectric constant and the conductivity can be determined by systems utilizing the random scattering that results from the relation of average backscattered power versus angle for wavelengths longer than 10 meters.

i. Groundwave measurements are not promising for airborne studies.

49. It was recommended that:

a. The attenuation and scattering effects of different kinds of vegetation at wavelengths in the order of 1 meter and longer be investigated. This is needed to determine the shortest wavelength that can be used for the different systems.

b. A study be made to determine the usefulness to trafficability of remote sensor systems that can resolve soil information only from terrain meeting certain restrictions. Specifically, it should be decided whether the ability to analyze (1) bare soil, (2) moss-covered soil, (3) homogeneous soil, (4) soil with a single subsurface interface, or (5) plane terrain is of sufficient importance to warrant a research and development effort on such capabilities.

c. If the study recommended in b above concludes that the restricted goals warrant a research effort, very-short-pulse systems, variable-frequency systems, and relative phase measurement systems should be studied under carefully controlled conditions.

Discussion

50. Dr. Barringer agreed with Dr. Nikodem's discussion and said that he hoped an antenna could be developed to focus a narrow beamwidth for P-band radar use in hilly terrain. Dr. Feder thought that any problem

concerning the mounting of large antennas on an aircraft could be solved. He stated that during flyover of hilly terrain, the angle of incidence will at some time be normal to the terrain. Also, the aircraft can fly parallel to the hilly range and gather useful information. Dr. Lattman said that hilly terrain is a problem because the soil varies continuously.

51. Dr. Feder felt that trafficability is more concerned with factors underneath vegetation than with vegetation itself. He said that while long wavelengths are needed to penetrate vegetation, shorter wavelengths can pass through small openings in the vegetation and read surfaces below it. The shorter wavelengths also give better resolution. Therefore, he suggested that the use of short wavelengths in vegetated areas not be discounted arbitrarily at this time.

52. Dr. Lattman asked how a signal from vegetation and one from soil can be distinguished. Dr. Nikodem said that very short wavelengths can differentiate between them. Mr. Shockley suggested that lasers might be used to pinpoint the difference between vegetation and soil.

53. Dr. Colwell said that vegetation might not be the insurmountable obstacle it appeared. He felt that more emphasis should be placed on identifying vegetation and implying subvegetation features. Lt Williams stated that soil charactéristics can be discerned from vegetation scatter, type, and distribution.

54. Mr. Addor said that many problems make it difficult to infer soil types from vegetation. He felt vegetation contains useful information, but the information is subtle, making it difficult to extract.

Proposed Projects and Future Plans

"Proposed Projects and Future Plans" (H. J. Nikodem)

55. Exhibit 3 presents the projects that are proposed and plans for the future in the Terrain Analyzer Program.

Discussion

56. Dr. Lattman questioned the accuracy claimed by Aero Service Corp. for the profilometer and asked what they used as a reference. Mr. Lundien

replied that a barometric altimeter was used for giving distance to the ground from an airplane. Dr. Nikodem added that the altimeter limited accuracy and that laboratory tests substantiated the accuracy of the laser for measuring relative altitudes. Lt Williams said that a profilometer mounted in an airplane had been used by Aero Service Corp. to measure 6-in. drops between consecutive benches of a football stadium. Mr. Shockley stated that measurements of terrain profiles have been made from an aircraft, using a laser profilometer, and that trees were easily detected. He noted that corrections were made for changes in altitudes and flight level, and added that these data are now being reduced by Aero Service Corp.

57. Dr. Colwell said he was not convinced that subsurface is the only place to look for factors affecting trafficability. He was impressed with vegetation as an indicator of slope, swamps, terrain, etc., and pointed out that the best trafficability routes can be chosen by photographic interpretation of vegetation cover. Mr. McLerran stated that arctic vegetations help show land type. Dr. Feder said that tests showed that more information was gathered from vegetation at angles of 60-deg incidence than at vertical incidence. Dr. Lattman emphasized that any information from sensors must be translated to maps.

58. Dr. Feder suggested that ultraviolet radiation should not be discounted totally as an airborne sensor, since recent studies have indicated that it is very sensitive to moisture.

59. Dr. Lattman asked if "go" or "no-go" information is important. Mr. Carlton replied that it is very important for airfields where construction time is at a premium and when decisions must be made on the level of construction effort necessary.

Concluding Session

60. After the technical presentations and group discussions were completed, the Board of Consultants met privately on the second day of the conference to formulate a formal report to the WES. This report (Exhibit 4) was presented by Dr. Barringer to the reassembled group. Mr. Shockley then adjourned the meeting.

PROGRAM

CONFERENCE OF THE BOARD OF CONSULTANTS ON
REMOTE TERRAIN ANALYSIS BY ELECTROMAGNETIC MEANS

U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

18-19 November 1965

Mr. W. G. Shockley, Chairman

18 November 1965

0830	Welcome	Colonel John R. Oswalt, Jr. Director
0840	Mobility and Environmental Division Research Programs	Mr. W. G. Shockley, Chief M&E Division
0855	Tour Terrain Analyzer Section	Mr. B. R. Davis, Acting Chief Terrain Analyzer Section
0935	Coffee Break	
0955	Active Infrared Studies	Mr. B. R. Davis
1010	Passive Infrared Studies	Mr. N. J. Lavecchia, Jr. Engineer, Instrumentation Br.
1025	Discussion of Infrared Studies	Group Participation
1105	Gamma-Ray Studies	Mr. A. N. Williamson, Physicist Terrain Analyzer Section
1125	Discussion of Gamma-Ray Studies	Group Participation
1200	Lunch	
1300	Radar Studies	Mr. J. R. Lundien, Engineer Terrain Analyzer Section
1320	Discussion of Radar Studies	Group Participation
1400	Dropped-Oscillator Studies	Mr. P. A. Smith, Physicist Terrain Analyzer Section
1415	Discussion of Dropped-Oscillator Studies	Group Participation
1440	Coffee Break	
1500	Factors Influencing Remote Determination of Soil Trafficability Conditions Using Radar and Radio Waves	Dr. H. J. Nikodem, Physicist Terrain Analyzer Section
1515	Discussion of Factors Influencing Remote Determination of Soil Trafficability Conditions Using Radar and Radio Waves	Group Participation

EXHIBIT 1

1540	Proposed Projects	Dr. H. J. Nikodem
1600	Discussion of Proposed Projects	Group Participation
1630	Adjourn	

<u>19 November 1965</u>

0830	Consultants' Time
1030	Consultants' Report
1200	Adjourn

ATTENDANTS

CONFERENCE OF THE BOARD OF CONSULTANTS ON
REMOTE TERRAIN ANALYSIS BY ELECTROMAGNETIC MEANS

U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

18-19 November 1965

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Department of the Army

Mr. M. V. Kreipke

Office, Chief of Engineers

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Consultants

Dr. A. R. Barringer, Barringer Research Ltd.
Dr. F. C. Bates, Saint Louis University
Dr. R. N. Colwell, University of California
Dr. A. M. Feder, Texas Instruments Inc.
Dr. L. N. Lattman, The Pennsylvania State University

U. S. Army Engineer Waterways Experiment Station

Participants

Colonel John R. Oswalt, Jr.
Mr. F. R. Brown
Mr. W. G. Shockley
Mr. S. J. Knight
Dr. D. R. Freitag
Mr. B. R. Davis
Dr. H. J. Nikodem
Mr. J. R. Lundien
Mr. A. N. Williamson
Mr. P. A. Smith
Mr. N. J. Lavecchia

Observers

Mr. A. A. Rula
Mr. M. P. Meyer
Mr. H. D. Molthan
Mr. E. A. Baylot
Mr. E. E. Garrett
Mr. E. E. Addor
Mr. J. H. Shamburger

EXHIBIT 2

PROPOSED PROJECTS AND FUTURE PLANS

Proposed Projects

1. The research thus far has been concerned primarily with the manner in which soil characteristics can be measured by a specific sensing device. However, soil is not the only component of the terrain that is of interest for mobility and trafficability determinations. Other terrain factors that must be considered are slope; vertical, lateral, and longitudinal obstacles; and hydrologic features.

2. These factors and methods by which the measurements relative to them are obtainable are discussed herein. After these various methods of obtaining measurements are examined, the projects considered to be of the highest priority are discussed and those that WES plans to investigate are indicated. The planned program deviates somewhat from the most desirable program because of limitations imposed by available funds and personnel.

3. The feasibility of measuring certain terrain factors with sensors operating in different regions of the electromagnetic spectrum, or with special measuring techniques, is estimated in table 1.

Terrain factor system

4. A number of terrain factor systems are listed in the first column of table 1. Three of these designations may be unfamiliar. Vertical obstacles refer to obstacles that force a vehicle to move chiefly in the vertical plane. Lateral obstacles are those that a vehicle must go around. Longitudinal obstacles are those in the path of a vehicle that cause it to decelerate as the obstacles are overridden or pushed aside.

Terrain parameters

5. The specific parameters used to define or measure a terrain factor have been listed in the second column. Soil mass strength and soil surface strength are considered or primary importance for evaluating trafficability, but the other parameters listed also are significant when the total off-road mobility problem is considered.

Gamma rays

6. The potential of gamma rays for measuring terrain parameters was

considered, and it was concluded that soil mass strength and soil surface strength probably were the only two parameters that could be determined. However, studies to date indicate that only such soil characteristics as parent material or mineralogical content, which may be related to soil type and strength, can be measured.

X-rays

7. X-rays cannot be used for remote sensing because of their high attenuation in the air and buildup from scattered gamma rays.

Ultraviolet, visible light, infrared

8. Ultraviolet, visible light, and infrared sensors have been grouped in the table since the usable measuring techniques and applicability of sensors operating within these regions are essentially the same. Three distinct measuring techniques are listed--passive radiation, laser illumination, and laser scanning. It can be seen that this wavelength region has capabilities of quantifying some terrain factors by either direct or relative measurements, but the ability to quantify soil parameters appears to be either severely limited or impossible, principally because the radiation does not penetrate vegetation and the soil surface.

Radar

9. Short-wavelength radar. A short-wavelength radar system has no distinct advantage over the ultraviolet, visible light, and infrared systems. However, it can be used to evaluate the scattering characteristics of soil surfaces at various angles of incidence and to measure the velocity of flowing water.

10. Long-wavelength radar. Long-wavelength radar systems, encompassing the spectral region from 10-cm radar waves to 100-meter waves, appear suitable for measuring some soil parameters related to trafficability, such as layer thickness and soil-moisture content, but only for certain conditions of surface roughness, surface undulations, and vegetation cover. The wide beamwidths make measurements of other terrain factors impossible.

Nuclear resonance

11. Nuclear resonance measurements seem suitable for determining moisture content and obtaining some indication of soil type. There are two ways of measuring moisture content. One, the resonance absorption method, would be

applicable only in the laboratory where an artificial, homogeneous magnetic field can be applied. In the second method, the hydrogen nuclei are excited to saturation by a pulsed magnetic field. A signal transmitted from these nuclei in the Lamor frequency would be detected and used to indicate moisture content and possibly soil type.

12. Since nuclear resonance measurements provide low resolution in both the horizontal and vertical planes, no other applications, except possibly water-depth determinations, are foreseen.

Dropped devices

13 The remaining columns in table 1 list some devices with special designs that employ a dropped device as a link in the analysis of terrain. These will be discussed later.

Summary of applicable wavelength regions

14 As stated, soil parameters are of primary interest in making mobility determinations. Table 2 gives the general limitations of remote soil sensing devices that use electromagnetic waves in the ultraviolet through the radio spectral region. It lists the desirable attributes of a system and indicates whether or not specific regions of the spectrum possess these.

15 With this assessment, table 3 lists the spectral regions suitable for making certain soil measurements on various types of terrain. From this table it is apparent that the limitations of the different wavelength regions vary, although, in some instances, only in degree. Knowledge of the usefulness of these wavelengths in discerning useful information is incomplete. Therefore, it is suggested that limitations of the long-wavelength radar system be analyzed further to define the types of terrain in which these systems would be best suited.

Future Plans

16. Projects that need study are listed in the following paragraphs in an approximate order of priority. Some of these studies are already in progress. They include:

a. Dielectric-constant measurement project

b. Gamma-ray project

c. Dropped-oscillator project

d. Radar vegetation project

Relations of dielectric constants to soil-moisture content

17. Several of the remote sensor systems considered capable of providing soil measurements would do so through measurements of the soil dielectric constant. More information is needed on the relation of the dielectric constant to soil-moisture content, soil type and temperature, and the frequency of the radiation. At the present time, a 1.074-kilomegacycle interferometer is being constructed specifically for measuring dielectric constant and conductivity of soils. With this instrument, the dielectric constant-moisture content and conductivity-moisture content relations will be studied in several soil types at different temperatures.

Swept-frequency radar system

18. The merits of the swept-frequency radar system already have been described. The ability of such a system to make remote soil-depth determinations should first be studied thoroughly with laboratory models and breadboard electronic circuitry, because of the expense of more elegant systems. Then a system could be designed for field and airborne use with specifications based on the laboratory studies. WES would like to initiate first phase studies of a swept-frequency system immediately, if adequate funds can be made available.

Gamma ray

19. Analysis of results of gamma-ray tests of soils should be continued. Additional soil and gamma-ray measurements will be made on soil samples selected from those already in the laboratory. From these, an attempt will be made to determine whether gamma-ray measurements can be related to usable soil parameters. If no useful correlation is found, no further tests will be made. Should correlation to some soil property be indicated, appropriate tests on in-situ soils will be made.

Magnetic nuclear resonance

20. The capabilities of magnetic nuclear resonance instruments for remote determination of soil moisture and/or soil type should be investigated.

It is believed that the investigation should begin in a modest way in the laboratory, but there are no specific plans for beginning such a study at this time.

Two-frequency radio

21. Measurements of the relative phase of two known frequencies in the 5- to 30-megacycle range appear promising for determining the dielectric constant by remote sensing. Vegetation and surface roughness have little influence on the phase-shift measurement because of the long wavelengths employed.

22. For the initial studies, measurements employing this technique are planned with scale models to study the effect of surface roughness. Field studies then will be conducted if they appear warranted. For these, antennas for the two transmitters and receivers will be mounted on the boom of a truck or on an elevated wooden platform.

Laser profilometer

23. A laser profilometer, operating with a continuous-wave laser modulated with a number of frequencies in the 1- to 50-megacycle range, should be able to measure vertical elevations, including wave height and vegetation height, along a flight path. It should be possible to scan with the instrument, within limits, normal to the flight path and to obtain readings not restricted to the flight line. A laser altimeter developed by Spectra-Physics Corp. and tested by Aero Service Corp. is claimed to have an absolute ranging accuracy within 0.1 to 0.2 ft. This accuracy cannot be approached by radar devices. Tests with this laser altimeter have been made within the last few months by Aero Service Corp. for WES. After these data have been analyzed, a decision will be made on the possibility of further work. At present, it seems likely that the work will be continued, although the source of funds is in doubt.

Dropped oscillator

24. The initial phases of the dropped-oscillator study were described earlier. This work will be continued, and deficiencies uncovered in the early tests will be corrected. In particular, the problem of air space along the shaft probably will require changing the shape of the shaft. Additional evaluation tests will be made in uniform soils, probably in the

laboratory. Later, tests will be conducted in layered soils to determine how the layers affect response. It is hoped that a practical field instrument with a transmitter system can be designed soon.

Radar vegetation

25. Before intensive study of radar systems for soil measurements can be justified, it must be determined if radar frequencies can be transmitted through vegetation and return a meaningful signal from the soil below. Studies are in progress to isolate the parameters that cause the wide variations that have been observed in the power transmitted through vegetation, and will be continued. Once the effects caused by vegetation have been defined, the effects of underlying soil can be determined and the inherent properties that govern trafficability more clearly defined.

Laser ground photography

26. Illuminating the ground with a laser beam would provide an increased mapping capability in the visible or infrared region of the spectrum by allowing the reflection coefficient to be measured independent of the sun's illumination. An instrument for this type of laser ground photography has been built by Perkin-Elmer Corp. under contract to Wright-Patterson Air Force Base.

27. If the laser radiation illuminating the ground were polarized, the depolarization effect of the reflecting surface might provide additional information for analysis.

28. Systems of this type may permit soil identification for bare ground and better identification of vegetation type, and perhaps fill the gap that has been found to exist in measuring the emissivity or reflectivity of passive infrared radiation. No laser ground photography studies are planned at this time.

Laser decelerometer

29. A laser-tracked penetrometer dropped from an airborne vehicle might be usable to measure the complete deceleration as the penetrometer strikes the ground. Such a penetrometer might consist of a mechanically movable shaft mounted inside a second shaft in such a way that the inner shaft is free to oscillate upon impact. The change in relative position of the two shafts, as the inner shaft oscillates, might be used to modulate a laser

beam and reflect it with an intensity suitable for detection with a photodetector.

Use of explosives

30. A multisensor device directed toward an explosion might detect--as a function of time--smoke cloud size and temperature, ejected particles and gases, shock waves, crater dimensions, temperature, and soil laid bare in the crater.

Use of mirrors

31. A unique technique that may have application to visibility and vegetation studies employs a dropped mirror in combination with either a laser altimeter or a dropped-light source. A rapidly rotating mirror or light source, mounted on a shock-absorbing platform, could scan the terrain in a plane parallel to the surface of the ground. Pictures of the illuminated terrain would be taken from the dropped source as it approaches the ground. No studies to develop this technique have been planned.

Personnel and funding problem

32. Since a comprehensive program to develop a system of remote sensors for determining soil trafficability conditions far exceeds the present and proposed funding and manpower levels, current plans are to place emphasis on the sensors thought to offer the best promise. For the most part, these are long-wavelength sensing devices suitable for directly obtaining quantitative data on subsurface soil conditions. Unless additional funding is made available, the remainder of the tasks must be deferred until they can be worked into the schedule.

33. The Board's views of this evaluation of the most promising and most needed systems will be appreciated. The members' recommendations will greatly influence both the trends of the research program and the amount of money devoted to the various components of that program.

Table 1

Remote Sensing Methods - Terrain Descriptors - Matrix

Terrain Factor System	Terrain Parameter	Gamma Rays	X-Rays	Ultraviolet, Visible Light, Infrared: Passive	Ultraviolet, Visible Light, Infrared: Active (Laser Illumination)	Ultraviolet, Visible Light, Infrared: Altimetry (Laser Scanned)	Radar: Short Wavelength	Radar: Long Wavelength	Nuclear Resonance	Dropped Devices: Pene-trometer	Dropped Devices: Oscillator	Dropped Devices: Mirror
Soil	Soil mass strength	R	Air attenuation prevents remote sensing	Limited penetration				R S	R	M	R	N
	Soil surface strength	R		Temperature influenced	R B	N	R B	R S	Low resolution, horizontal and vertical	M	N	N
Slope	Slope	Source material only in soil		M St-Ph	M St-Ph	M	M	Low resolution, horizontal		N	N	N
Vertical obstacles	Height			M St-Ph B	M St-Ph B	M B	M B			N	N	N
	Width			M St-Ph B	M St-Ph B	M B	M B			N	N	N
	Length			M St-Ph B	M St-Ph B	M B	M B			N	N	N
	Spacing			M St-Ph B	M St-Ph B	M B	M B			N	N	N
	Approach angle			M St-Ph B	M St-Ph B	M B	M B			N	N	N
	Mass strength			Limited penetration						M	N	N
Lateral obstacles	Spacing			M Ph	M Ph	M	M			N	N	M
	Stem spread			M Ph	M Ph	M	M			N	N	M
	Branching height			M St-Ph (?)	M St-Ph (?)	M (?)	N			N	N	M (?)
	Clustering			M St-Ph	M St-Ph	N	N			N	N	M
Longitudinal obstacles	Spacing			Ph	Ph	M	M			N	N	M
	Stem diameter			R St-Ph	R St-Ph	R	R			N	N	M
	Bending strength			R St-Ph	R St-Ph	R	R			N	N	R
	Clustering			M St-Ph (?)	M St-Ph (?)	N	N			N	N	M
	Soil mass strength			Limited penetration				R		M	N	N
Hydrologic features	Depth			Limited penetration		M	M	M	R	M	N	N
	Approach angle			M St-Ph	M St-Ph	M	M	N	N	N	N	N
	Current velocity			R	R	N	M	N	N	N	N	N
Visibility	Index			N	N	N	N	N	N	N	N	N

R - Related parameter measurable
M - Directly measurable

Ph - Photography
St-Ph - Stereo-photography

B - For bare soil only
S - For smooth terrain only

N - Not for this purpose

Table 2

Remote Soil-Sensing Limitations

Desirable Attributes	Ultraviolet Visible Light Infrared	Radar		Radio	
		1-10 cm	10 cm-1 m	1-10 m	10-100 m
a. Good resolution	Yes	Yes ?	No	No	No
b. Absolute amplitude measurable through vegetation	No	No	No	Yes ?	Yes
c. Relative amplitude measurable through vegetation	No	No	Yes?	Yes	Yes
d. Applicable in hilly terrain	Yes	Yes	Yes ?	No	No
e. Responsive to soil layers	No	Yes ?	Yes	Yes	Yes
f. Moisture of surface layer measurable	Yes	Yes	Yes	Yes	Yes ?

Table 3

...cability of Wavelength Regions

Terrain Type		Soil Property to be Measured	Ultraviolet Visible Light Infrared	Radar		Radio		Relevant Desirable Attributes (See Table 2)
				1-10 cm	10 cm-1 m	1-10 m	10-100 m	
Bare soil small area	Plane or hilly terrain	Top-layer moisture	Yes	Yes ?	No	No	No	a, f
Large areas of bare soil	Plane terrain	Layer thickness	No	Yes ?	Yes	Yes	Yes	e
		Top-layer moisture	Yes	Yes	Yes	Yes	Yes ?	f
	Hilly terrain	Layer thickness	No	Yes ?	Yes ?	No	No	d, e
		Top-layer moisture	Yes	Yes	Yes ?	No	No	d, f
Vegetation-covered soil	Plane terrain	Layer thickness	No	No	Yes ?	Yes	Yes	c, e
		Top-layer moisture	No	No	No	Yes ?	Yes ?	b, f
	Hilly terrain	Layer thickness	No	No	Yes ?	No	No	c, d, e
		Top-layer moisture	No	No	No	No	No	b, d, f

REPORT OF THE BOARD OF CONSULTANTS ON
REMOTE TERRAIN ANALYSIS BY ELECTROMAGNETIC MEANS

The Board of Consultants on Remote Terrain Analysis by Electromagnetic Means met on 18-19 November 1965 at the U. S. Army Engineer Waterways Experiment Station (WES) in Vicksburg, Miss. Board members present were: Dr. A. R. Barringer, Chairman, and Drs. F. C. Bates, R. N. Colwell, A. M. Feder, and L. H. Lattman. The purpose of the meeting was to act on data presented by the WES, under the direction of Mr. W. G. Shockley, Chief of the Mobility and Environmental Division, WES. This report was produced following the 18 November 1965 meeting on the Remote Sensing Program.

Comments on Results to Date

The members of this Board have been impressed with the amount and quality of research in remote sensing of terrain completed to date at the WES. The findings and basic data produced by several of these studies are unique and of great value to the broad field of remote sensing, as well as to the immediate objectives of the U. S. Army in terrain analysis. The work reflects competent scientific and engineering leadership, efficient and economical execution, and thorough, workmanlike interpretation and presentation.

Additional Work on Existing Results

The Board recommends that the base of the WES remote sensing research be expanded and more thoroughly integrated with related data already in existence at WES, and with various remote sensing programs elsewhere. The first step toward achieving the objectives of this general recommendation should be preparation of a two-part summary report as follows:

a. Part 1. The multisensor research results produced to date by Terrain Analyzer Section. This part should be in addition to any reports prepared to date, and should emphasize gains to be made by coordinating information from the various spectral regions.

b. Part 2. Correlation of these multisensor data with environmental data as produced elsewhere in the Mobility and Environmental Division.

EXHIBIT 4

The body of knowledge gathered by the WES and skills and hardware for working in various bands of the electromagnetic spectrum must be integrated now to obtain the maximum benefits from the work already done. In addition to those bands studied at the WES, the results of investigations made elsewhere must be reviewed and collated. Two immediate and very important advantages incident to such a program are:

a. All parts of the spectrum receive an equal and thorough review, so that no part is omitted or slighted by lack of interest by a particular investigator.

b. Correlation between spectral bands may yield results that no single band, or uncorrelated group of bands, can yield; for example, the use of one band to calibrate another, or a determination of relative information yielded by different bands recording similar features under possible variations of factors, such as climate, vegetation, and exposure.

After it is developed, a remote sensor system cannot be finally evaluated in the laboratory, but must be tested in the environment in which that sensor is ultimately to be used. This has been established by the Air Force Cambridge Research Laboratories (AFCRL) SATAN study and subsequent efforts. Part 2 of the integrated study should therefore strive to reevaluate already existing sensor research data in terms of field environments, e.g. potential combat areas in humid, tropic regions.

Many studies tacitly presume that a particular sensor will measure a desired parameter better than any other sensor, regardless of conditions. Studies of the type here recommended will indicate the validity or lack of validity of this concept.

It is suggested that a program be undertaken to review the large volume of recent material available on remote sensing. Many organizations within the Federal Government have completed excellent studies on remote sensing, particularly AFCRL, the Advanced Research Projects Agency (ARPA), U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency (GIMRADA), National Aeronautics and Space Administration (NASA), U. S. Geological Survey (USGS), and others. The Infrared and Optical Sensing Laboratory, Institute of Science and Technology, University of Michigan, has collected extensive data on "passive" infrared sensing, and has published three transactions of symposia on remote sensing. The Navy Radiological Defense Laboratory (NRDL) has recent records on ultraviolet sensing.

An enormous body of information exists, in Government agencies and elsewhere, on sensing in the visual part of the spectrum. Our greatest experience in remote sensing is in this part of the spectrum, and a thorough background in this band must be a part of the WES research effort. In addition, conventional aerial photographs serve as the best base maps for plotting information obtained by all other sensors.

Any budget allotted to such collation and reviews should contain a reasonable travel allowance so that members of the WES research group may attend symposia, visit other research laboratories, and pursue all leads.

Contact must be established with other agencies flying remote sensors, so that information obtained may be made immediately available to the WES remote sensing workers and special data accumulated for the WES team. Particularly important is the obtaining and collating of complete area evaluation reports, such as SATAN. Such reports include integrated soil, vegetation, hydrologic, and geologic analyses.

The foregoing portion of the total program should be allocated at least one man-year. To expedite, it is suggested that one or more persons be assigned at the earliest possible time to this work on a full-time basis.

The total program envisioned by the Board includes both a short-range and a long-range approach. The specific recommendations pertinent to each are as in the following.

Short-Range Effort

There is an immediate need for the development of a preliminary remote sensing system concept to obtain usable trafficability information. The capability exists at WES to develop and test this concept in six months to one year. The concept should evaluate the sensors to be used and specify methods by which the data can best be interpreted. The previous work done by the WES group and other workers is here of paramount importance.

It is recommended that work be concentrated on the following data (or sensing regions) for this short-range effort:

a. Conventional aerial photography (0.4 to 1.0 microns)

b. Passive infrared data (8 to 14 microns)

c. Radio data (1 to 3 meters)

These three regions have been the most thoroughly studied and are ready for coordinated field research by the WES group and development into a prototype usable system concept in the shortest time. They are discussed in more detail below. Indoor laboratory work should be minimized here, and used not for basic research, but to support the field effort.

The early acquisition of a suitable aircraft, the instrumentation of that aircraft with developed and promising sensors as indicated, and the familiarization of WES personnel with the skillful use of this platform is strongly recommended.

Long-Range Effort

Spectral bands

The Board of Consultants makes the following appraisal of the potentiality and direction of long-range research within the various spectral bands.

Gamma ray. It is recommended that on-the-ground investigations be carried out, using existing equipment adapted for field use. It is further recommended that efforts be coordinated with existing airborne gamma-ray programs such as the P2V and AEC programs in order to obtain data that can be regionally coordinated with the trafficability of a terrain.

X-ray. No further effort should be devoted to investigations in the X-ray bands because of the low level of solar-induced terrestrial radiation, and restrictions on size and bulk of airborne power supplies.

Ultraviolet. The significance of moisture absorption bands has already been established at WES and elsewhere. Ultraviolet radiation in the 0.28- to 0.4-micron region is particularly moisture sensitive. It is therefore recommended that such available research documents as those produced by NRDL (e.g. the SALMON Project) and by the NASA-USGS efforts be reviewed.

Visible. The value of conventional aerial photography in remote sensing for both data and positioning must not be overlooked. The huge body of data already in existence at WES and throughout other agencies, as well as the literature on the subject, should be reviewed and integrated into the program. It is not here suggested that the Terrain Analyzer Section now undertake a basic research and development effort in this spectral band, but that it develop sufficient skill to take full advantage of information existing and

being developed by other agencies such as AFCRL, and be able, if necessary, to specify an exact effort as part of a complete program. For example, WES should be able to specify film-filter combinations to be used so that conventional photography can be best integrated into, and complement, any specific research effort involving other sensors. In this connection, AFCRL has available a nine-lens camera which may be used by WES during part of an AFCRL flight.

The recent development of the laser profilometer should be recognized for its possible value in vertical positioning of airborne platforms and in providing specific and useful information on topography and surface roughness. Evaluation leading to possible inclusion of this instrument in terrain analysis systems should be effected.

Infrared - photographic (0.7 to 1.0 microns). In efforts such as the NRDL SALMON Project, the value of photographic infrared, and particularly infrared Ektachrome, was established to be closely akin to that of ultraviolet in depicting discrete differences in moisture content of soils and vegetation. It also has certain operational advantages over ultraviolet, such as greater haze penetration. In addition, the unique value of photographic infrared for identifying certain vegetation types that could be indicative of military trafficability conditions has long been recognized.

It is therefore recommended that WES resources be expanded in investigating the value of data collected in this band for use in complementing those obtained through use of the more sophisticated sensors.

Infrared - reflective (1.0 to 5.5 microns). Imagery now can be obtained out to 2.8 microns using vidicon techniques. Strong moisture absorption bands exist at 1.4 and 1.94 microns. It is feasible to construct ratio-imagery equipment using one of these bands and an adjacent reference. As evidenced by WES research, such imagery would provide a highly sensitive indication of surface moisture. It is recommended that existing spectral profiles on natural vegetation acquired by the Barrier and Intrusion Branch (formerly Mines Detection Branch) of the U. S. Army Engineer Research and Development Laboratories be studied, along with WES data on soils, with objectives oriented towards evaluating the potential of this spectral region.

It is believed that sufficient laboratory spectrometer data are now available in this region and further laboratory experimental work is not

warranted at this time.

Infrared - emitted (3.5 to 15 microns with special reference to 8 to 14 microns). As previously indicated, a great deal of work has been, and is being, done at the University of Michigan, USGS, and elsewhere. The Board unanimously recommends that this very important spectral region should play a major role in both the short- and long-range efforts of WES.

Radio waves

The Board recommends that the Terrain Analyzer Section at this time emphasize active systems. In addition, the Board recommends that polorization information already produced be reviewed and additional signature information achievable in γ versus θ curves as a function of polarization be studied for possible benefits. This should be supported by a theoretical study (one man-month).

V-band. This band is subject to severe atmospheric attenuation which limits the operational range. The Board recommends that it be given no attention at this time.

Ka-band. The Board recommends the following program:

a. Continue Ka-band testing oriented toward obtaining first-surface soil information by propagation through vegetation interspaces.

b. Review existing data to provide first-surface scattering information that may be useful in controlling and interpreting longer wavelength penetration data.

c. Continue testing to establish value for vegetation identification (e.g. to complement and control analogous photographic data).

d. Continue testing for data to use in establishing microrelief parameters (e.g. ripple-mark shapes and orientation from cardinal effects).

K_u-band. This band is subject to severe atmospheric absorption and operational problems. The Board recommends it be given no attention at this time.

X-band. The Board recommends continuing use of X-band systems in conjunction with any other radio wavelengths being tested in the Terrain Analyzer facility

a. because of its value as a control,

b. because these data are easy to obtain and likely to have future value, and

c. because of possible use for comparison with the large volume of

X-band data produced by other investigators (e.g. Cosgriff et al, at Ohio State University).

C-band. The Board recommends continued testing

a. for the same reasons given for X-band,

b. for possible value of C-band data where even limited penetration has been achieved,

c. for evaluation of a C-band and P-band correlation system for obtaining first subsurface interface depth information, recognizing that such application could be limited, and

d. in anticipation of S-band research.

S-band or L-band. The Board recommends that an analysis be performed on existing C- and P-band data to extrapolate values of S- and L-bands, and if results are promising, a Terrain Analyzer Research type system be prepared by modifying X-band or C-band system components (new antennae will probably be the primary additional components required).

The Board further recommends that these bands be tested for penetration advantages over C-band, and if advantages are sufficient, use these bands, in conjunction with P-bands, to establish soil strata or water-table depth measurement ability.

P-band. Work carried out to date has given promising results in the P-band region. There are indications that it should be possible to design a system which can resolve layering in the uppermost 2 ft of soils and measure dielectric constants. It has also been indicated that the dielectric constant bears a close relationship to soil moisture content. It is recommended, therefore, that the current Terrain Analyzer Research Program be expanded to include groundborne field measurements. This should be supported by a program for measurement of dielectric constants in the existing laboratory, as is already planned.

Coordination should be maintained with NASA, the Cold Regions Research and Engineering Laboratory (CRREL), and any other groups working on VHF reflectivity programs to minimize duplication of effort.

VHF-LF radio. The Board recommends that WES provide approximately three man-months for literature survey and pertinent evaluation of these wavelengths, compared with P-band. In this evaluation, restricting operational considerations (e.g. antenna coupling) need be emphasized.

Conductivity measurements at wavelengths longer than 1000 meters. Consideration should be given to the measurement of conductivity profiles from low-flying aircraft. Terrain conductivity can provide valuable information, for example, on the distribution of clays, muskeg, swamps, and caliche. Airborne maps can readily be produced using inductive electromagnetic methods. These techniques are well established in the field of airborne geophysical exploration. Consideration should also be given to using radio fields transmitted by the high-powered Navy VLF stations which now give worldwide coverage. The FCC has produced soil conductivity maps for the entire U. S. which could be profitably studied.

Transceiving technology

Considerable new data on FM and monopulse broadcast and signal processing technology have been researched and developed over the past few months. It is recommended that:

a. Available data be reviewed and technically evaluated. (This should require a six-man-month engineering effort, with sufficient travel provisions.)

b. Promising breadboards and more advanced hardware be borrowed (or time-shared in situ) for comparative testing for data collection performance. Continued development of data from the Terrain Analyzer Section's variable-frequency system prototype is included here.

c. Most promising techniques be evaluated for operational utility.

d. Airborne test models be constructed and tested.

Pertinent to transceiving modes, the Board recommends that certain reported sensor performance conclusions be reconsidered, with regard to possibilities for using several sensor vehicles as part of a single operational system, and for propagating energy normal to sloped terrain surface, though not necessarily normal to the horizontal plane of flight.

Explosives and defoliation

The use of explosives to expose surface and subsurface soils has been established. It is recommended that an active investigation of this technique be made by the Terrain Analyzer Section as an exploratory effort.

This category of research should include such subjects as the use of vegetation defoliants and dehydrators to provide better exposure of soil cover to certain sensors (e.g. shorter wavelength radar).

Ground truth

In order to make an adequate evaluation of the effectiveness of any remote sensing equipment or techniques, accurate on-the-ground information must be obtained. A large volume of correlated remote sensing and field data is currently being compiled by many organizations, such as the Office of Space Sciences and Applications of NASA, at test sites. The Board recommends that these data be investigated, for they are critical in extrapolating remote sensor information into areas inaccessible to ground teams.

The Board views the acquisition of ground truth as an important use of dropped oscillator and similar contact systems. In addition, such contact systems may be quite valuable for calibration of airborne sensors and, on occasion, may provide data for points otherwise inaccessible. Repeated flights over the same terrain under different meteorological and vegetational conditions are important as sensors must be "calibrated" over a range of natural conditions. Similarly, some sensors may give more or less information than others over the same terrain under different conditions. It is recommended that the investigation of such systems be diligently pursued for use complementary to total remote sensing.